HIGH-STRENGTH CONCRETE INCORPORATING COPPER SLAG AND GROUND PUMICE

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Certificate of Original Authorship

I certify that work in this thesis has not previously submitted for a degree nor has it been submitted as part of requirement for a degree except as fully acknowledged with the text.

I certify that work in this thesis has been written by me. Any help that I have received in my research work and the preparation of this thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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PUBLICATIONS

My publications under name of University of Technology Sydney (UTS) during my studentship are:

1. Chloride-Induced Corrosion of Submerged Concrete Structures in Marine Environment, International Conference on Corrosion and Prevention, Australian Corrosion Association, Brisbane, Australia, 10-13 November, 2013. (conference)

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ABSTRACT

Nowadays, concrete is the most widely used construction material which mainly consists of Portland cement, aggregate and water. For more than 200 years, concrete has been known as a durable and high strength construction material while its formability during its fresh stage results in building different shapes which are otherwise not possible. Due to widespread construction of high-rise buildings, bridges and other concrete structures, there is a growing demand from clients as well as technical requirements for using high-strength concretes in certain applications such as towers.

However, common belief is that more Portland cement should be used for obtaining a higher strength grade. In other words, producing high-strength concrete is synonymous with higher consumption of Portland cement. But, cement production is a high energy-consuming and polluting process to the extent that Portland cement production, on its own, contributes to over 7% of worldwide greenhouse gases (GHG) which is equal to 1.6 billion tonnes of GHGs. On average, production of each tonne of Portland cement results in releasing one tonne of CO_2. Current average consumption of concrete is about one tonne per year per every living human being. Because of large consumption of concrete and Portland cement as well as its energy-consuming and polluting production process, even small reductions in greenhouse gas emissions per tonne of manufactured concrete can make a significant and positive global impact.

Recent research shows that Portland cement and coarse aggregates have the highest environmental impacts and greenhouse gas emissions. Therefore, any attempt to make concrete more sustainable should firstly focus on these two materials.

On the other hand, using traditional materials such as natural limestone aggregate for producing concrete causes many environmental problems and such procedures are critically under scrutiny in terms of sustainability because it is not possible to renew these natural sources. Therefore, new procedures must be developed to use alternative raw materials for producing concrete.

Pumice is a volcanic rock which is made of highly vesicular rough textured volcanic glass. According to US Geological Survey Report, global production of pumice and pumicite was approximately 18 and 17 million tonnes in 2011 and 2012, respectively. Traditionally, pumice as aggregate has been used for producing light weight building blocks, concrete and assorted building products in construction industry. However, technical performance and properties of concretes with pumice aggregate conveys important concerns because of high water absorption of pumice aggregate. On the other hand, main chemical ingredient of pumice is SiO_2 and many researchers have reported that pozzolanic characteristics for pumice powder and its positive effects on mechanical and long-term properties of concrete. Therefore, it can be a good alternative cementitious material which can be used instead of Portland cement.

Copper slag is a by-product obtained during the matte smelting and refining of copper. Production of one tonne of copper produces around 2.2-3 tonne of copper slag. In the United States, the amount of copper slag manufactured is approximately four million tonnes, and in Japan is around two million tonnes per year. Although some researchers have attempted to use copper slag powder as a cement additive, a significant part of deposited copper slag is air-cooled slag which results in crystallised structure instead of required amorphous structure for a cement additive. Furthermore, many researchers have reported promising results by using copper slag as coarse aggregates in concrete. This research aims to develop a novel type of green high-strength concrete by using copper slag coarse aggregate and pumice powder with less environmental impacts and carbon footprint with at least similar performance to common high-strength concrete. To achieve this purpose, a comprehensive assessment of results of an extensive experimental program on fresh and hardened concrete specimens including slump, unit weight, air content, compressive and splitting tensile strength measurements was undertaken.

16 different mixture proportions based on different levels of cement replacement with pumice and using copper slag instead of limestone coarse aggregate at two water to binder ratios of 0.3 and 0.4 were investigated. In addition, silica fume was used at level of 10% of cement weight in some mixtures. Compressive strength of concrete specimens were measured at different ages of 7, 28, 56 and 91 days while splitting tensile strength was measured at 7, 28 and 91 days to evaluate effects of pumice, copper slag and their combinations.

In general, it can be concluded that the presence of copper slag can increase compressive strength of concrete at different ages. This can be attributed to higher level of strength properties displayed by copper slag aggregate. In addition, the surface texture of coarse aggregate is partly responsible for the bond between the cement paste and aggregate because of the mechanical interlocking between cement paste and copper slag. At age of 91 days, all of concrete mixtures, except those containing finely ground pumice as 20% of Portland cement replacement, showed approximately similar or even better performance in comparison with control mixtures.

In general, it can be concluded that using copper slag coarse aggregate increased the splitting tensile strength of concrete by around 12% in comparison with control mixtures with limestone coarse aggregate. In addition, adding finely ground pumice resulted in rapid reduction of the splitting tensile strength at all ages. However, satisfying results were obtained by combined use of pumice powder and copper slag coarse aggregate.

With regard to numerous test results of fresh and hardened high-strength concrete with and without copper slag coarse aggregate and finely ground pumice, it can be recommended that the most efficient and optimized value of finely ground pumice when copper slag coarse aggregate is used in concrete is 10% at water to binder ratio of 0.4 and 20% at water to binder ratio of 0.3 with the presence of 10% silica fume in concrete mixture. The 28-day compressive and splitting tensile strength were similar to control normal concrete with limestone coarse aggregate while at later ages they displayed superior performance in comparison with the control normal mixture in terms of compressive and splitting tensile strength. The recommended values of pumice and copper slag showed promising and excellent results at the age of 56 days which is the common age of measuring concrete properties including high level of supplementary cementitious materials. In this study, 30% of Portland cement was successfully replaced by silica fume and finely ground pumice while copper slag coarse aggregate as an industrial waste material was simultaneously used instead of whole of natural limestone coarse aggregate for producing sustainable high-strength concrete. With regard to the

Green Building Council of Australia's Green Star Mat-4, this novel type of high-strength concrete can achieve concrete credits as green concrete.